transceivers in the LMS with an antenna height product of 10 meters (as indicated in ITU-R Recommendation M.1039-1), the results also apply to non-GSO MSS sharing with fixed LMS transceivers that have the same technical characteristics, including the antenna height product.

3.2.1 Effects of interference into LMS receivers

For land mobile systems, circuit availability may range from 90 to 99%, with the higher values applicable to critical communications such as fire or safety. Availability degradation of an additional 0.1% due to NGSO MSS shared use of frequency bands may be considered acceptable by some users. For 100 ms transmissions by the NGSO MSS, this would translate to one interference event every 100 seconds, or approximately once every 2 minutes.

The short duration of potential non-GSO MSS interference into LMS receivers further mitigates the effects of the interference. A 100 millisecond interference into analog voice may not affect message intelligibility, and for digital systems, the short interference burst may be eliminated by some error correction techniques.

3.3 Interference from land mobile stations into non-GSO MSS satellites

Narrowband non-GSO MSS networks will use dynamic channel assignment techniques to avoid channels being actively used by land mobile stations. Thus as long as the dynamic channel assignment system correctly identifies all active land mobile channels, there is no possibility of interference from land mobile stations into non-GSO MSS satellites. The analysis in Annex 2 section 4 examined if there would be a sufficient number of unused, clear channels available to support non-GSO MSS operations.

A simulation program was used to determine the number of land mobile stations within the satellite footprint that can operate in the shared spectrum and still provide a minimum average of 6 clear channels per satellite for the non-GSO MSS uplinks. Four different land mobile station activity factors, three land mobile channelization plans, and three MES uplink data rates were considered. The results indicate that with 6.25 kHz land mobile system channelization, 2.4 kbps MES uplink data rate, and 0.003 Erlang activity factor, 190 000 terrestrial mobile stations could operate within the satellite footprint (12 million km^2) and still leave a minimum of 6 clear channels for MES uplink transmission in 1 MHz of shared bandwidth. For the same conditions, but in 5 MHz of shared bandwidth, 1.5 million terrestrial mobile stations could operate.

These results indicate that frequency sharing, as modeled in this analysis, could allow the non-GSO MSS below 1 GHz networks to find sufficient clear channels to operate.

4. Conclusions

The results of these analyses and simulations show that frequency sharing between narrowband, Earth-to-space links for non-GSO MSS below 1 GHz networks and land mobile services would produce infrequent interference to the land mobile service in frequency bands below 1 GHz, with LMS characteristics as modeled. An additional result is that frequency sharing between narrowband non-GSO MSS below 1 GHz networks and land mobile services could allow the non-GSO MSS networks to find

sufficient clear channels to operate Earth-to-space. The conclusion is that it is feasible for narrowband non-GSO MSS uplinks using DCAAS to share spectrum with land mobile services in the bands below 1 GHz that have low erlang levels in the LMS and for services that accept an additional 0.1% availability degradation. Further study, however, may be necessary to ascertain the effects to terrestrial mobile relay systems where characteristics of the terrestrial systems may be different than modeled in this analysis.

Based upon these results a preliminary draft new ITU-R recommendation is given in Annex 1.

Text suitable for inclusion in the WAC-97 Report is in Annex 3.

ANNEX 1

Preliminary Draft New Recommendation

METHOD FOR THE STATISTICAL MODELING OF FREQUENCY SHARING BETWEEN STATIONS IN THE MOBILE SERVICE BELOW 1 GHZ AND FDMA NON-GEOSTATIONARY SATELLITE ORBIT(NON-GSO) MOBILE EARTH STATIONS

(Questions ITU-R 83-3/8, 84-3/8, and 201/8)

The ITU Radiocommunication Assembly,

considering

a)   that Resolution 214 (WRC-95) invited the ITU-R to study and develop Recommendations on the technical and operational issues relating to sharing between services having allocations and the non-GSO MSS below 1 GHz in the bands proposed to WRC-95 and in other frequency bands;

b)   that the spectrum already allocated or being considered for allocation by World Radio Conferences for low-earth orbit (LEO) mobile-satellite services (MSS) below 1 GHz, if shared with mobile services, must provide adequate protection from harmful interference;

c)   that LEO MSS can provide beneficial radio-based services, including emergency alerting (see Note 1), to a large community of travelers;

Note 1 - However, these services will not be identified as safety services as defined by the Radio Regulations.

d)   that the use of LEO enables practical use of frequencies below 1 GHz by space stations;

e)   that some coordination and channelisation techniques used in fixed and mobile radio systems in bands below 1 GHz can lead to low erlang loading on individual channels;

f)   that dynamic channel assignment techniques are technically feasible and may provide a means of spectrum sharing between mobile services and low power, low duty cycle mobile-satellite services;

g)   that the users would operate throughout large geographic areas;

h)   that the transmission of the MES are short bursts;

i)   that the signal characteristics in the MSS below 1 GHz may allow co-channel sharing with mobile and fixed service networks,

recommends

1.   that the statistical modeling methods described in Annex 1 be used to evaluate frequency sharing between stations in the mobile services below 1 GHz and FDMA non-geostationary satellite orbit mobile earth stations in the same frequency band.

ANNEX 1

Statistical Modeling of Frequency Sharing Between Stations in the Mobile Service Below 1 GHz and Mobile-Satellite Service (MSS) Earth Station Transmitters

1.   Introduction

This Annex describes a method to be used to determine if mobile-satellite service (MSS) earth station transmitters can share spectrum with mobile services. Mobile services in the bands below 1 GHz are typically characterized by voice and data carriers that may be analog or digitally modulated and are assigned on a periodic channel grid. Channel spacings used include 6.25 kHz, 12.5 kHz, and 25 kHz. The MSS systems would perform Earth-to-space transmissions using short-term bursts on an intermittent basis with a low duty cycle. (It has been indicated that burst lengths might be up to 500 ms). The duration of time over which such transmissions would take place is under study (1% in 1 - 15 minutes has been suggested). MSS systems below 1 GHz may use a dynamic channel assignment algorithm which allows the space station to identify those channels not occupied by the mobile stations which are sharing the spectrum. A receiver in the satellite monitors the entire shared frequency band and determines which segments of the spectrum are currently being used by the LMS system or for non-GSO MSS uplinks. With the band-scanning receiver on board the satellite, there is very little chance for interference from mobile earth stations to land mobile system receivers. There are, however, several circumstances where the dynamic channel assignment technique would fail to identify an active LMS channel: 1) LMS power level below the detection threshold of the satellite band-scanning receiver, 2) blockage on the path from the LMS transmitter to the satellite so the received signal level is not high enough to be detected, 3) a LMS transmitter begins operation on a channel during a MSS transmission on what had previously been measured as a clear channel. The methodology in section 2 provides calculation of the probability of interference to a LMS receiver from MES transmissions, given that the dynamic channel assignment technique has not identified an active channel for the reasons given above, or for any other reason.

The other possibility for mutual interference is LMS transmissions interfering into the MSS space station receiver. With the MSS band scanning receiver identifying clear Earth-to-space channels for MES use, this type of interference can be avoided.

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Section 3 provides a statistical method that can be used to provide assurance of finding a sufficient number of clear channels to carry the MSS earth-to-space transmissions. However, there remains the possibility of an LMS transmitter beginning operation on a previously clear channel during the short interval of a MES transmission on that channel , and thereby potentially causing interference into the space station receiver.

2. Statistical Modeling of interference from non-geostationary satellite orbit, mobile-satellite service, mobile earth stations (NGSO MSS MESs) into land mobile stations

The following statistical model determines the probability of interference without dynamic channel assignment being used. This worst case assumption provides an upper bound on the actual probability of interference for NGSO MSS networks with dynamic channel assignment.

The input parameters are:

a) Land Mobile Channelization Plan (25, 12.5 or 6.25 kHz) - Used to determine land mobile link center frequency and receiver IF bandwidth as shown in Table 2-1.

Table 2-1. Land Mobile Channelization Plans

Channelization Plan	IF Bandwidth
25 kHz	16 kHz
12.5 kHz	8 kHz
6.25 kHz	4 kHz

b) MES Uplink Data Rate (9.6, 4.8, or 2.4 kbps) - Used to determine the MES transmit spectrum as shown in Figure 2-1 and transmit power as shown Table 2-2.
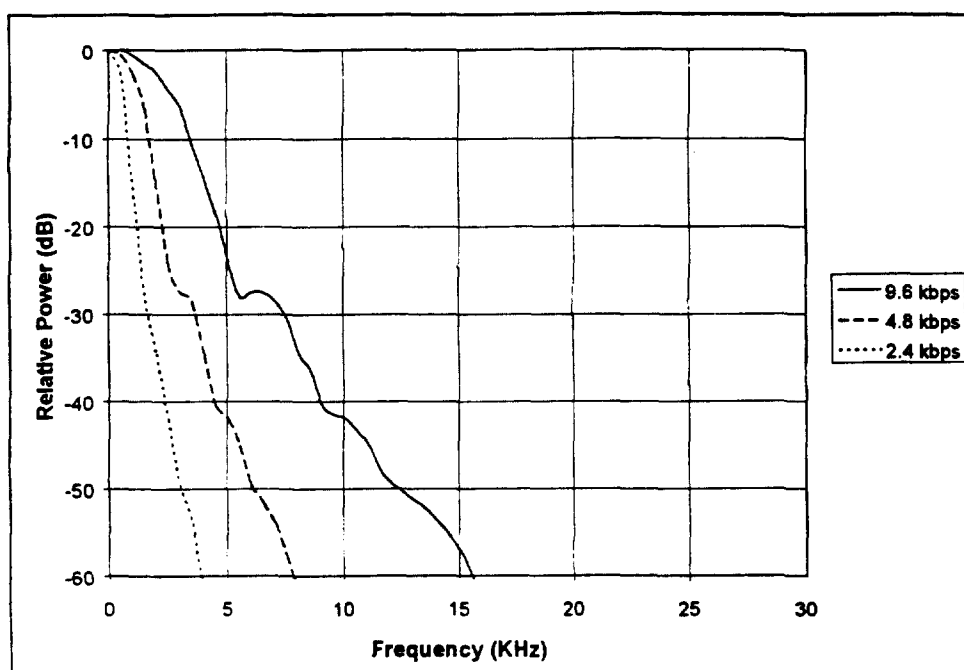
Figure 2-1. MES Transmit Signal Masks

Table 2-2. MES Transmit Powers

Data Rate	Transmit Power
9.6 kbps	7 W
4.8 kbps	3.5 W
2.4 kbps	1.75 W

c) *MES Distribution (Uniform or Clustered)* - The uniform distribution models the MESs as uniformly distributed over the land area within the MSS satellite uplink beam. The clustered distribution places the MESs within the satellite beam with probability density roughly proportional to population density.

d) *MES Channel Selection (Random or Interstitial)* - For the random selection algorithm, the MSS uplink channels are selected randomly on a 2.5 kHz grid across the entire frequency band to be shared (1MHz, for example). For the interstitial algorithm, the MSS uplink channels are restricted to interstitial locations between the land mobile channels.

For a given set of input parameters, a sufficient number of ½-second trials are performed to insure that the computed probability of interference is reliable. For each ½- second trial the following steps are performed:

1. A land mobile transmitter location is randomly selected as the center of one of the 20 most populous cities within the MSS satellite uplink beam.

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2. The land mobile receiver location is randomly selected using a circular mass distribution from 0 to 20 km from the transmitter location.

3. A land mobile link center frequency, CF_{LM}, is randomly selected in a 1 MHz bandwidth based on the input land mobile channelization plan.

4. The land mobile receiver IF bandwidth, B_{IF}, is determined from the input channelization plan.

5. The distance between the land mobile transmitter and the land mobile receiver, d_{LM}, is computed.

6. 128 active MESs are randomly selected each ½-second within the satellite beam using the input distribution, either uniform or clustered. This corresponds to over 22 million MES transmissions per day from the beam coverage area, which assumes that the NGSO MSS system is operating at 100% of theoretical capacity. This is another worst case assumption.

7. The distances, d_{MES-LM}, from each of the MESs to the land mobile receiver are computed.

8. Center frequencies, CF_{MES}, are randomly selected in a 1 MHz band for each of the MESs using the input selected method, uniform or interstitial.

9. The MES effective isotropic radiated power spectrum, $EIRP_0(f)$, is determined based on the input data rate.

10. The carrier-to-noise-plus-interference ratio is computed as follows:

$$C/(N+I) = \cfrac{\cfrac{10^{3.204}\,W}{d_{LM}^4}}{10^{-15.07}\,W + \displaystyle\int_{CF_{LM}-\frac{B_{IF}}{2}}^{CF_{LM}+\frac{B_{IF}}{2}} \sum_{MESs} \frac{10^{2.815}\cdot EIRP_0(CF_{MES}-f)}{d_{MES-LM}^4}\,c}$$

11. If C/(N+I) is less then 10.7 dB then the trial is deemed to have resulted in interference.

The probability of interference is computed as the ratio of the number of trials resulting in interference divided by the total number of trials. This result is the probability of interference to the LMS receiver if it were to be receiving transmissions continuously.

For cases with low LMS traffic loading, the probability of interference is reduced by the Erlang factor for the channel.

3. Modeling of interference from land mobile stations into NGSO MSS satellites

Narrowband non-GSO MSS networks will use dynamic channel assignment techniques to avoid channels being actively used by land mobile stations. Thus as long as the dynamic channel assignment system correctly identifies all active land mobile channels, there is no possibility of interference from land mobile stations into non-GSO MSS satellites. This model examines if there would be a sufficient number of unused, clear channels available to support non-GSO MSS operations.

The simulation determines the number of land mobile stations in the satellite beam that can operate in the shared spectrum and still provide a minimum average of 6 clear channels per satellite for the NGSO MSS uplinks. This worst case assumption provides a lower bound on the number of land mobile stations that can operate in the shared spectrum while still allowing the NGSO MSS network to operate at 36% of theoretical capacity.

The input parameters are:

a) Land Mobile Channelization Plan (25, 12.5 or 6.25 kHz) - Used to determine land mobile station center frequency grid, and land mobile transmit spectrum as shown in Figure 3-1.
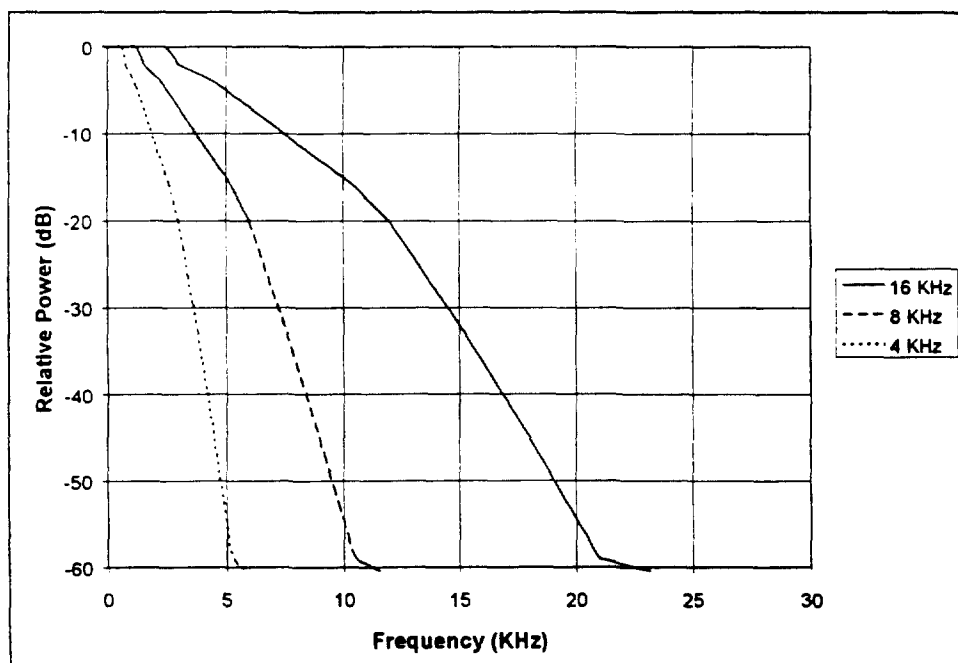

Figure 3-1. Land Mobile Station Transmit Signal Masks

b) MES Uplink Data Rate (9.6, 4.8, or 2.4 kbps) - Used to determine the NGSO MSS uplink center frequency grid as shown in Table 3-1.

Table 3-1. MES Uplink Channel Bandwidths

Data Rate	Channel Bandwidth
9.6 kbps	15 kHz
4.8 kbps	10 kHz
2.4 kbps	5 kHz

c) Amount of shared spectrum (1 MHz or 5 MHz).

d) Land mobile station average activity factor (0.01, 0.003, 0.001, or 0.0003 Erlang).

For each set of input parameters, the following steps are performed:

1. The initial number of land mobile stations is set to 1,000.

2. The land mobile stations are randomly distributed across the area covered by the satellite uplink beam.

3. The land mobile transmitter effective isotropic radiated power spectrum, $EIRP_0(f)$ is determined based on the input land mobile channelization plan.

4. The NGSO MSS satellite system uplink channel bandwidth, BW, is determined based on the input MES uplink data rate.

5. For each trial, the NGSO MSS satellite constellation is randomly rotated in time, a sufficient number of trials are performed to insure that the computed number of land mobile stations is reliable. The following steps are performed:

    A.   For each land mobile station, a transmit center frequency, CF_{LMS}, is randomly selected in the input amount of shared spectrum, 1 MHz or 5 MHz, based on the input land mobile channelization plan.

    B.   For each land mobile station and for each NGSO MSS satellite the Doppler frequency shift, $\Delta f_{Doppler}$, is computed.

    C.   For each NGSO MSS satellite and for each NGSO MSS uplink channel center frequency, CF_{CH}, in the input amount of shared spectrum, the interference-to-noise ratio is computed as follows:

$$(I/N)_{CH} = 10^{6.25} \cdot \int_{CF_{CH}-\frac{BW}{2}}^{CF_{CH}+\frac{BW}{2}} \sum_{LMSs} EIRP_0(CF_{LMS} + \Delta f_{Doppler} - f) df$$

D.   For each NGSO MSS satellite, the number of clear channels is computed as the sum of those with I/N < 10 dB.

6. If the minimum of the computed numbers of clear channels is greater than 6, then the number of land mobile stations is increased by 1,000 and the above procedure is repeated starting at step 2.

7. The process is completed when the maximum number of LMS stations that still allows for 6 clear channels is found.

APPENDIX A
TO ANNEX 1

Example applications of the statistical models

1. Introduction

This Appendix shows examples of application of the two statistical models contained in this recommendation.

The example non-GSO MSS network used has the following characteristics: 48 satellites in 8 orbital planes inclined 50 degrees to the equator; each plane contains six equally spaced satellites in 950 km altitude circular orbits; narrowband frequency division multiplexing for the Earth-to-space transmissions; operation in a store-and-forward mode; transmissions within 500 ms frames containing digital packets; satellite use of a band scanning receiver to implement a dynamic channel activity assignment system (DCAAS) that assigns unused channels to earth stations for uplink transmissions; and uplink data rates of 2.4, 4.8, and 9,6 kbps. It is assumed that the system is operating at maximum capacity over a specific geographic area, (for this example, 22 million Earth-to space packet transmissions per day over the contiguous United States).

The land mobile stations modeled have the following characteristics: analogue, frequency modulation system (or digitally modulated, binary-FSK system); a vertically polarized antenna having 0 dBi gain towards the satellite; minimum received signal power assumed to be -140 dBW; and channel bandwidths of 6.25, 12.5 and 25.0 kHz with low erlang loading on individual channels. The technical characteristics used in the model are for LMS systems operating in the bands 138-174 MHz, 406-420 MHz, 450-512 MHz, 806-821 MHz, 821-824 MHz, 851-856 MHz, and 866-869 MHz.

2. Potential interference from non-GSO MSS earth stations into land mobile stations

The distance between the land mobile station and its base station is modeled by a circular mass distribution from 0 to 20 km with 20 km corresponding to threshold received power. Both uniform and clustered distribution of MSS earth stations are considered. A 1 MHz shared frequency band is assumed with both random and interstitial uplink channel selection algorithms considered.

Table A-1 shows the upper bound probability of interference computed by the simulation program for the range of parameters examined. The significance of the raw probabilities may be difficult to interpret, so they have been converted to mean time between interference events as shown in Table A-2. Results in Tables A-1 and A-2 are for the condition that the land mobile station is operating continuously. Table A-3 shows the mean time between interference events for a typical land mobile user with 0.01 Erlangs of traffic.

Table A-1. Probability of Interference

Land Mobile Channelization	MES Uplink Data Rate	Uniform Distribution		Clustered Distribution	
		Random Selection	Interstitial Selection	Random Selection	Interstitial Selection
25 kHz	9.6 kbps	0.00038	0.000055	0.0013	0.00020
	4.8 kbps	0.00025	0.0000058	0.00088	0.000022
	2.4 kbps	0.00016	0.00000093	0.00052	0.0000034
12.5 kHz	9.6 kbps	0.00023	0.00019	0.00075	0.00064
	4.8 kbps	0.00012	0.000020	0.00039	0.000069
	2.4 kbps	0.000067	0.0000024	0.00023	0.0000084
6.25 kHz	9.6 kbps	0.00014	0.00015	0.00049	0.00051
	4.8 kbps	0.000094	0.00011	0.00032	0.00037
	2.4 kbps	0.000066	0.000074	0.00023	0.00026

Table A-2. Worst Case (Smallest) Mean Time Between Interference Events

Land Mobile Channelization	MES Uplink Data Rate	Uniform Distribution		Clustered Distribution	
		Random Selection	Interstitial Selection	Random Selection	Interstitial Selection
25 kHz	9.6 kbps	22 min	*3 hours*	7 min	42 min
	4.8 kbps	34 min	*24 hours*	10 min	*7 hours*
	2.4 kbps	50 min	*150 hours*	16 min	*41 hours*
12.5 kHz	9.6 kbps	36 min	44 min	11 min	13 min
	4.8 kbps	70 min	*7 hours*	22 min	120 min
	2.4 kbps	130 min	*60 hours*	36 min	*17 hours*
6.25 kHz	9.6 kbps	60 min	55 min	17 min	17 min
	4.8 kbps	90 min	75 min	26 min	23 min
	2.4 kbps	130 min	120 min	36 min	32 min

Table A-3. Mean Time Between Interference Events For Typical Push-to-Talk User (0.01 Erlang)

Land Mobile Channelization	MES Uplink Data Rate	Uniform Distribution		Clustered Distribution	
		Random Selection	Interstitial Selection	Random Selection	Interstitial Selection
25 kHz	9.6 kbps	*37 hours*	10 days	*11 hours*	*69 hours*
	4.8 kbps	*56 hours*	100 days	*16 hours*	26 days
	2.4 kbps	*83 hours*	*21 months*	*27 hours*	68 days
12.5 kHz	9.6 kbps	*60 hours*	*73 hours*	*18 hours*	*22 hours*
	4.8 kbps	*120 hours*	29 days	*36 hours*	*200 hours*
	2.4 kbps	*210 hours*	*8 months*	*60 hours*	71 days
6.25 kHz	9.6 kbps	*100 hours*	*92 hours*	*28 hours*	*28 hours*
	4.8 kbps	*150 hours*	*130 hours*	*43 hours*	*38 hours*
	2.4 kbps	*210 hours*	*190 hours*	*60 hours*	*53 hours*

3. Potential interference from land mobile stations into non-GSO MSS satellites

The model of section 3 of the annex of this recommendation performs a simulation to determine the number of land mobile stations within the MSS satellite uplink beam that can operate in the shared spectrum and still provide a minimum average of 6 clear channels per satellite for the MSS uplinks. The minimum average per satellite assumption is worst case, since the average over all of the visible satellites will be greater than the minimum average, and thus provides a lower bound on the number of land mobile stations that can operate in the shared spectrum. The satellite footprint is roughly the size of the contiguous United States, 12 million km^2.

Four land mobile station average activity factors were considered, 0.01, 0.003, 0.001, and 0.0003 Erlang[1]. These correspond to averages of 432, 130, 43, and 13 minutes per month of land mobile station transmissions, respectively. Assuming a 0.4 voice activity factor, the equivalent conversation times are 1,080, 325, 108, and 33 minutes per month. Note that the averages are over the entire population of land mobile stations and over the entire month.

Table A-4 shows lower bounds on the number of land mobile stations in the contiguous United States operating in 1 MHz of shared spectrum computed by the simulation program for the range of parameters examined.

Table A-5 shows the lower bounds assuming 5 MHz of shared spectrum. The lower bounds are significantly greater than 5 times those for 1 MHz of shared spectrum.

Table A-4. Lower Bound Number of Land Mobile Stations in 1 MHz of Shared Spectrum

Land Mobile Channelization	MES Uplink Data Rate	Land Mobile Station Average Activity Factor			
		0.01 Erlang	0.003 Erlang	0.001 Erlang	0.0003 Erlang
25 kHz	9.6 kbps	12,000	38,000	120,000	380,000
	4.8 kbps	17,000	55,000	170,000	550,000
	2.4 kbps	23,000	77,000	230,000	770,000
12.5 kHz	9.6 kbps	16,000	52,000	160,000	520,000
	4.8 kbps	24,000	80,000	240,000	800,000
	2.4 kbps	35,000	120,000	350,000	1.2 million
6.25 kHz	9.6 kbps	18,000	60,000	180,000	600,000
	4.8 kbps	35,000	120,000	350,000	1.2 million
	2.4 kbps	58,000	190,000	580,000	1.9 million

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[1] Erlang is a measure of traffic intensity. In this context it is a measure of the land mobile station utilization.

Table A-5. Lower Bound Number of Land Mobile Stations in 5 MHz of Shared Spectrum

Land Mobile Channelization	MES Uplink Data Rate	Land Mobile Station Average Activity Factor			
		0.01 Erlang	0.003 Erlang	0.001 Erlang	0.0003 Erlang
25 kHz	9.6 kbps	110,000	370,000	1.1 million	3.7 million
	4.8 kbps	125,000	420,000	1.3 million	4.2 million
	2.4 kbps	170,000	570,000	1.7 million	5.7 million
12.5 kHz	9.6 kbps	115,000	380,000	1.2 million	3.8 million
	4.8 kbps	190,000	630,000	1.9 million	6.3 million
	2.4 kbps	255,000	850,000	2.6 million	8.5 million
6.25 kHz	9.6 kbps	120,000	400,000	1.2 million	4.0 million
	4.8 kbps	230,000	770,000	2.3 million	7.7 million
	2.4 kbps	450,000	1.5 million	4.5 million	15 million

ANNEX 2

NVNG MSS

Uplink Band

Sharing Analysis

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September 10, 1996

NVNG MSS Uplink Band Sharing Analysis

Appendices

1.0 Introduction and Summary

This study analyzes the feasibility of frequency sharing between the non-voice non-geostationary (NVNG) mobile satellite service (MSS) uplinks and the Land Mobile Service. The uplink transmissions of a narrowband (FDMA/TDMA) NVNG MSS system were simulated in the presence of Land Mobile Service operations to determine the probability of interference to Land Mobile Services and to determine the availability of channels for the NVNG MSS. The results of this study show that narrowband NVNG MSS systems can successfully share spectrum with Land Mobile Services consistent with characteristics used in the models. These results can be generalized to multiple narrowband NVNG MSS systems simultaneously co-frequency sharing with Land Mobile Services.

The 148 - 149.9 MHz, 455 - 456 MHz, and 459 - 460 MHz bands are allocated for NVNG MSS uplinks and for Land Mobile Service links on a co-primary basis. Thus there is the potential for interference, both from NVNG MSS Mobile Earth Stations (MESs) into land mobile stations and from land mobile stations into NVNG MSS satellites. Other bands below 1 GHz that are allocated to the Land Mobile Service are also being considered for allocation to the NVNG MSS on a co-primary basis.

NVNG MSS networks use duty cycle limitations, with active avoidance of frequencies being used by Land Mobile Services for narrowband NVNG MSS networks or with uplink radiated power flux density limits for spread spectrum systems, to mitigate the potential for interference to and from Land Mobile Services. Narrowband NVNG MSS networks use highly sensitive band-scanning receivers and predictive algorithms to identify land mobile channels that will be clear, unused, during the next uplink frame time. These channels are then assigned to NVNG MSS MESs to use for uplink bursts. This technique minimizes the possibility of interference into the land mobile stations and into the NVNG MSS satellites.

This report uses Monte Carlo simulations to provide high fidelity analysis of the frequency sharing potential between narrowband NVNG MSS networks and the Land Mobile Service. The simulation studies were performed at 149 MHz and at 460 MHz, the results are representative of all potential NVNG MSS frequencies below 1 GHz. Three land mobile station transmit signal models, representative of the six land mobile channelization plans commonly encountered below 1 GHz, were used. They are typical of the system characteristics provided by the Land Mobile community as part of the Working Party 8D process.

Section 2 describes the system models used. The analysis and simulation results are presented in Sections 3 and 4 for the interference into Land Mobile Services and for the interference into NVNG MSS satellites, respectively. Appendix A provides a sensitivity analysis of the satellite band-scanning receiver and Appendix B contains a detailed description of the simulations.

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Section 3 shows that frequency sharing between narrowband NVNG MSS networks and Land Mobile Services will result in negligible interference with the Land Mobile Services with characteristics as modeled. Section 4 shows that frequency sharing between narrowband NVNG MSS networks and Land Mobile Services will allow the NVNG MSS networks to find sufficient clear channels to operate. The results of this study show that narrowband NVNG MSS networks can successfully share spectrum with Land Mobile Services, with characteristics as modeled.

2.0   System Models

The Leo One USA NVNG MSS network is used as a representative example of a narrowband NVNG MSS network. It operates as a store-and-forward system. The mobile earth stations (MESs) transmit digital data packets to the satellites where they are stored in digital memory. At the appropriate time the satellite retransmits the packets to other MESs or to gateway earth stations. The gateways provide access to and from the terrestrial telecommunications network and act as packet relay stations. The satellite constellation is described in Section 2.1 and the associated MESs are described in Section 2.2. Generic land mobile station models are used as described in Section 2.3, they are representative of the six land mobile channelization plans commonly encountered below 1 GHz.

2.1   NVNG MSS Satellite Constellation

The NVNG MSS constellation consists of a total of 48 satellites in eight orbital planes equally spaced around the equator and inclined at 50°. Each plane contains six equally spaced satellites in 950 km altitude circular orbits.

The satellites are designed to communicate with MESs that see the satellite above a 15° elevation mask angle. The satellite antenna has a circular polarized iso-flux pattern with a G/T of -30.6 dB/°K at the sub-satellite point. The iso-flux pattern compensates for slant range variation within the satellite footprint, insuring that all users experience the same high level of performance.

Each satellite supports one 24 kbps subscriber downlink and 15 subscriber uplinks with data rates of 9.6, 4.8, or 2.4 kbps. In addition, each satellite supports one gateway uplink and one gateway downlink both operating at 50 kbps. All communications is simplex using one of two packet formats: Network (32 bytes) or Monitoring (100 bytes). The Network packets are used for resource request and assignment, and other network control functions. The Monitoring packets are used for monitoring applications and short, 80 byte, message applications.

The satellite subscriber downlink signal is partitioned into 500 millisecond (msec) frames. The satellites use a band scanning receiver to identify up to 15 clear uplink

2

frequency channels during each 500 msec frame for assignment to MESs during the next frame. Each frame is divided into two time slots. The first time slot is 50 msec in duration and is reserved for Network packets. During this time slot the satellite broadcasts the following information:

- ID of uplink frequency channel to be used for Network packets
- IDs of up to 14 clear uplink frequency channels available for uplink of Monitoring packets using slotted-ALOHA
- Confirmation of Network and Monitoring packets received during the previous frame.

During the remaining 450 msec time slot the satellite transmits Monitoring packets addressed to MESs in its footprint. The 450 msec time slot allows for up to 13 Monitoring packets.

2.2   NVNG MSS MES

The MES have 0 dBi gain vertically polarized antennas. The MES are capable of operating at three uplink data rates as shown in Table 2-1, which also shows the 99% power containment bandwidth and transmit power associated with each of the data rates. The transmit signal masks are shown in Figure 2-1.

Table 2-1. MES Uplink Parameters

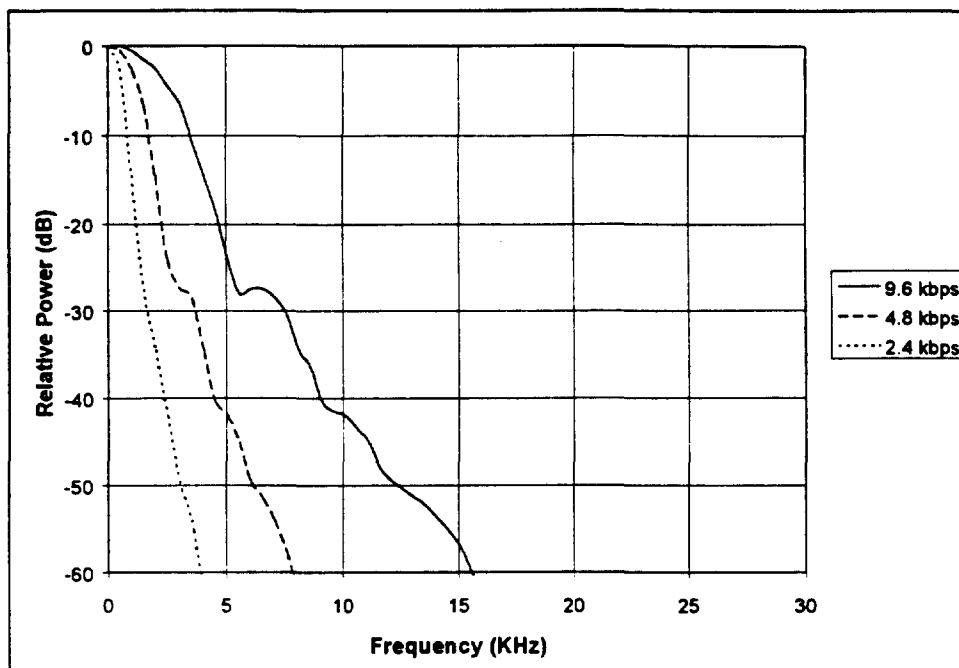| Data Rate	99% Power Containment Bandwidth	Transmit Power
9.6 kbps	8.2 kHz	7 W
4.8 kbps	4.1 kHz	3.5 W
2.4 kbps	2.05 kHz	1.75 W

Figure 2-1. MES Transmit Signal Masks

Each satellite is capable of receiving 15 uplink frequency channels, one for Network packets and 14 for Monitoring packets, at 9.6 kbps, 4.8 kbps, or 2.4 kbps. MESs that want to send Network packets divide the 500 msec interval starting coincident with the receipt of the first bits of the downlink frame into twelve 41.67 msec slots. Each MES then randomly selects one of these slots and transmits its packet on the uplink frequency assigned by the satellite for network control. If the MES does not receive a Network packet from the satellite acknowledging receipt of its packet within one second, then the MES waits for a randomly selected number of time slots and then retransmits its packet. MESs send Network packets to acknowledge receipt of a Monitoring packet or to register their location.

MESs that want to send a Monitoring packet divide the 500 msec interval into five 100 msec slots. Each MES then randomly selects one of these slots and transmits its packet on a randomly selected uplink frequency channel assigned by the satellite for Monitoring packets. If the MES does not receive a Network packet from the satellite acknowledging receipt of its packet within 1 second, then the MES waits a randomly selected number of time slots and retransmits its packet.

2.3   Land Mobile Station

Three generic land mobile station (LMS) models, corresponding to three channelization plans, are considered. They are typical of the system characteristics provided by the Land Mobile community as part of the Working Party 8D process. Common to all three are:

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- 6 dBi vertically polarized antenna
- minimum received signal power at edge of coverage of -140 dBW
- demodulator threshold of C/(N+I) = 10.7 dB

It is assumed that the antenna gain in the direction of the NVNG MSS satellites is 0 dBi. The 10.7 dB demodulator threshold corresponds to the FM threshold for analog signals and to a 10^{-3} bit error rate for non-coherently demodulated binary-FSK digital signals without forward error correction. For analog FM receivers, operation below the demodulator threshold results in individual clicks at the audio output, which rapidly merge into a crackling sound as the SNR continues to decrease. For digital FSK receivers, operation below the demodulator threshold results in degraded voice quality. Presumably, critical control data networks use forward error correction, short packets, parity checks, and retransmission protocols; and are not effected by occasional error bursts.

The three land mobile channelization plans and associated signal bandwidths are shown in Table 2-2. The LMS signal masks are shown in Figure 2-2. The results for 30 kHz, 15 kHz, and 7.5 kHz channelization plans are very similar to those obtained for the 25 kHz, 12.5 kHz, and 6.25 kHz plans, respectively. Thus the results of this study are applicable to all six of the LMS channelization plans commonly used below 1 GHz.

Table 2-2. Land Mobile Station Parameters

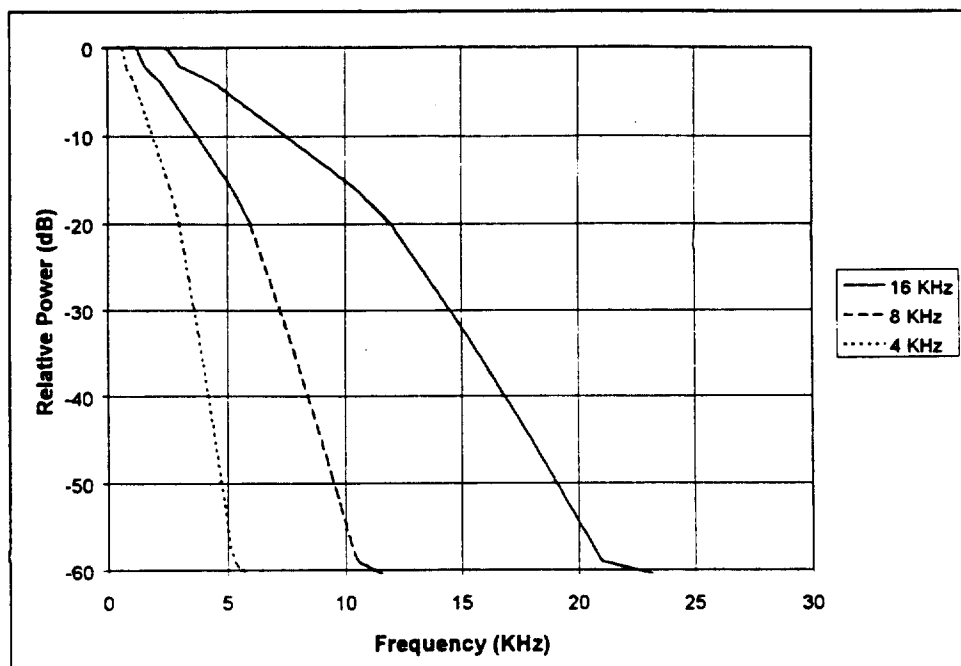| Channelization Plan Grid	Signal Bandwidth
25 kHz	16 kHz
12.5 kHz	8 kHz
6.25 kHz	4 kHz

Figure 2-2. Land Mobile Station Transmit Signal Masks

3.0 Interference from NVNG MSS MES into Land Mobile Stations

Narrowband NVNG MSS networks will use dynamic channel assignment techniques to avoid channels being actively used by land mobile stations. Thus as long as the dynamic channel assignment system identifies all active land mobile channels, there is no possibility of interference from NVNG MSS MESs into land mobile stations. The remainder of this section focuses on the potential interference if the dynamic channel assignment system fails to identify an active land mobile channel. This could occur as the result of low power land mobile station transmissions or as the result of blockage between the land mobile station transmitter and the NVNG MSS satellite. The sensitivity of the satellite band-scanning receiver is discussed in Appendix A.

The probability of a given land mobile station experiencing interference is a function of the NVNG MSS operating rate, the distance between the land mobile station and its base station, the distance between the land mobile station and the nearest active NVNG MSS MES, and the offset between the land mobile station receiving frequency and the NVNG MSS MES frequency. The probability of a given land mobile station experiencing interference is independent of the number of land mobile stations in the band.

A simulation program has been developed to determine the probability of interference assuming that dynamic channel assignment is not used. This worst case assumption provides an upper bound on the actual probability of interference. The NVNG MSS network was modeled as operating continuously at 100% of theoretical capacity, 8 million monitoring packets per day from the CONUS. This is another worst case assumption. Note that with the NVNG MSS network's slotted-ALOHA uplink protocol this capacity corresponds to over 22 million packet transmissions per day from the CONUS since at capacity an average of only 36% of the transmitted packets are received error free. The details of the simulation are provided in Appendix B.

The distance between the land mobile station and its base station is modeled by a circular mass distribution from 0 to 20 km, with 20 km corresponding to threshold received power. Two distributions of NVNG MSS MESs were considered, uniform and clustered. The uniform models the MESs as uniformly distributed across the CONUS. The clustered distributes the MESs across the CONUS with probability density roughly proportional to population density.

A 1 MHz shared frequency band was assumed with the land mobile station channel randomly selected in accordance with the land mobile channelization plan. Two NVNG MSS network uplink channel selection algorithms were considered, random and interstitial. For the random selection algorithm, the NVNG MSS network uplink channels were selected randomly on a 2.5 kHz grid across the entire 1 MHz band. For the interstitial selection algorithm, the NVNG MSS network uplink channels were restricted to the interstitial locations between the land mobile channels.

Table 3-1 shows the upper bound probability of interference computed by the simulation program for both the uniform and the clustered MES distributions. For each distribution, the three land mobile channelization plans (25 kHz, 12.5 kHz, and 6.25 kHz spacing), the three MES uplink data rates (9.6 kbps, 4.8 kbps, and 2.4 kbps), and the two NVNG MSS network uplink channel selection algorithms (random and interstitial) were considered.

The significance of the raw probabilities is difficult to interpret, so they have been converted to mean time between interference events as shown in Table 3-2. The land mobile user observes an interference event as a "click" or "pop". Since the land mobile environment is typically noisy, it is unlikely that the user would be able to distinguish an occasional "click" or "pop" due to MES transmissions from environmental background noise radiated by automobiles, power-generating facilities, and industrial equipment.

Table 3-2 shows that as expected, the uniform distribution provides more optimistic results. For the 25 kHz and 12.5 kHz land mobile channelization plans, the interstitial selection provided significantly reduced interference. For the 6.25 kHz channelization plan, the interstitial selection actually provided slightly increased interference. This is because with the small 6.25 kHz channelization, the interstitial selection always results in interference with two land mobile channels even for the 2.4 kbps NVNG MSS uplink data rate.

For random selection, the mean time between interference events ranges from 7 minutes to 130 minutes depending on MES distribution, land mobile channelization, and MES uplink data rate. For interstitial selection, the mean time ranges from 13 minutes to 150 hours. By limiting the MES uplink data rate to 4.8 kbps for bands with 12.5 kHz land mobile channelization plans and to 2.4 kbps for bands with 6.25 kHz plans, and using the appropriate selection algorithm, it is possible to achieve a minimum mean time between interference events of 36 minutes even for the clustered MES distribution.

These values assume that the land mobile station is operating continuously. If the land mobile station is operated at typical push-to-talk rates of less then 0.01 Erlang[1], then the typical land mobile station would experience an interference event at most once every 2.5 days. Table 3-3 shows the mean time between interference events for a typical land mobile user.

It is important to note that all of these results are based on the assumption that the NVNG MSS network selects uplink channels without regard to land mobile usage. Since in general the NVNG MSS network will be able to identify active land mobile channels, the actual interference from NVNG MSS MESs into a given land mobile station will be negligible. Appendix A shows that the satellite band-scanning receiver is

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[1] Erlang is a measure of traffic intensity. In this context it is a measure of the land mobile station utilization.